Beam-beam simulations with beamstrahlung for FCC-ee

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Acknowledgments:
Kazuhito Ohmi, Katsunobu Oide, Dmitry Shatilov, Demin Zhou, F. Zimmermann
→ Dynamic effects: Analytical estimations / simulations
→ Beam-beam simulations with beamstrahlung in SAD

1) @ 182.5 GeV
2) @ 45.6 GeV

→ Conclusions and perspectives
\( \text{Dynamic Effects -I} \)

\( \rightarrow \textbf{Dynamic effects}: \) Change of the Twiss parameters due to the beam-beam quadrupolar focusing

\( \rightarrow \) These effects are enhanced by running at half or full integer resonances

\( \rightarrow \) Two dynamic effects: dynamic beta and dynamic emittance

\( \rightarrow \textbf{Dynamic beta}: \)

\[
\begin{pmatrix}
\cos \mu & \beta \sin \mu \\
-\frac{1}{\beta} \sin \mu & \cos \mu
\end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -\frac{1}{\beta_0} \sin \mu_0 & \cos \mu_0 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ -\frac{1}{\beta} & 1 \end{pmatrix}
\]

- The beam-beam parameter \( \xi_{x,y} = \frac{\beta_{0(x,y)}}{4\pi f_{x,y}} \)

- \( \frac{1}{f_{x,y}} \) is the beam-beam interaction strength

- \( \beta_{x,y} = \frac{\beta_{0(x,y)}}{\sqrt{1-(2\pi \xi_{x,y})^2 + 4\pi \xi_{x,y} \cot(\mu_{0(x,y)})}} \); where \( \mu_{0(x,y)} = 2\pi \nu_{0(x,y)} \)
Dynamic Effects -II

Analytical estimations predict:

- 50% reduction in $\beta_x$ and 44% reduction in $\beta_y$ @ Top energies
- 34% reduction in $\beta_y$ @ Z energy

Above estimations were confirmed by a thin quadrupole insertion at both IPs in both lattices

Vertical misalignments of sextupoles were introduced to create the x-y coupling overall the ring

Dynamic emittance [1] could also be predicted in presence of radiation and vertical emittance

Predictions: 38% enhancement of $\epsilon_x$ and 43% enhancement of $\epsilon_y$ @ Top

Weak strong beam-beam simulations were performed by the SAD [2] version of BBWS [3].
Beam-beam elements were inserted at both IPs with beamstrahlung flag ON.
The crossing angle is simulated, the crab waist is employed for the weak beam.
The Strong beam is not crab waisted.

@ 182.5 GeV: (first lattice version)
- Weak beam population $N_p = 10^5$

- Physical apertures are inserted including synchrotron masks in the interaction region
- Vertical misalignments of sextupoles
- Tracking over 1000 turns
- Update strong beam parameters every one damping period (50 turns)

![Graph showing $\tau = 12.2 \pm 1.82$ mins]

Beamstrahlung simulations II

Energy of lost particles as a function of their loss position in the ring

→ Loss map was constructed (need higher statistics)

→ Losses are mainly concentrated around the IP (± 5 m) in the vertical plane

→ Collimators are needed to protect the IR from the above losses
→ Dynamic effects could be observed in the non-linear beam-beam simulations

→ Results are different from linear beam-beam simulations

→ How do these results appear without beam-beam element insertion??
No beam-beam

- Remove the beam beam element and track in the lattice in the presence of sextupole misalignments.

- Vertical emittance is now almost twice the design value.

- Reason: Residual coupling/dispersion at FRF & IP due to sextupole misalignments.

- Correction of residual coupling/dispersion is needed.
Due to strong beam-beam at Z, beam sizes at the IP will blow up.

Bootstrapping will be considered where injection will be done on stages.
Beamstrahlung at Z (II)

→ Represent the bootstrapping by simulating beam parameters after beamstrahlung and bootstrapping

→ 20 slices : Large beam-beam effect → large emittance blow-up → Beam loss

→ The bunch length is around 30 times larger than the interaction region

→ Number of slices should be high to correctly represent the beam-beam interaction
Slicing of the strong beam has a big effect on the blowup
But the blowup is still large and causing a large beam loss
Is it again the residual dispersions and xy couplings?
→ Remove the vertical sextupole misalignments and instead do artificial excitation/damping of the weak beam

→ Blow-up decreases significantly and no beam losses over 10000 turns

→ The blow-up thus is not due to the beam-beam itself but due to the residual dispersions and x-y coupling resulting from the vertical sextupole misalignments

→ The residuals are higher at Z due to the higher x-y coupling (Higher RMS of sextupole misalignments)
Correction Methods

- Local corrections were considered for our studies (IP and FRF)
- **Two methods are currently being considered:**
  1) Optimize the skew quadrupole components of the 2N sextupoles upstream/downstream of the to-be-corrected location to suppress dispersions/couplings at the latter
  
  2) Set randomly the skew quadrupole and skew sextupole components of all the sextupoles to create the needed xy coupling and to guarantee a negligible dispersion/coupling at the IPs and FRF
  
  3) Not to forget the anomalous equilibrium emittance due to the residuals of chromaticity corrections [4]

- Work is currently in progress
- Error and correction studies overall the ring were carried by S. Aumon (Presentations by T. Tydecks and T. Charles)

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[4]“Anomalous equilibrium emittance due to chromaticity in electron storage rings”, Katsunobu Oide and Haruyo Koiso, Physical review E, VOLUME 49, NUMBER 5
Conclusions

→ Dynamic effects has been analytically estimated and cross checked with a thin quadrupole insertion at both IPs for Top and Z energies

→ Beamstrahlung lifetime and loss map were simulated with a multi-turn tracking simulation

→ Losses were mainly concentrated in the IR at \( \pm 5 \, m \) from the IP

→ Collimators are necessary to protect the IR from losses from Beamstrahlung

→ Residual dispersions/x-y couplings due to vertical sextupole misalignments create a vertical emittance blow-up at IP that need to be corrected
→ Analytical calculations of the dynamic horizontal emittance using [1] to compare to simulations

→ Further continuation of the correction studies for the residual dispersion/coupling

→ After understanding the above, go for collimation studies (position, aperture and material)

→ With Ohmi san, try to do some beam-beam studies during the SuperKEKB commissioning in the next few months if possible
Thank you for your attention